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THE ROLE OF CHAOS IN HEMISPHERIC PROCESS AND ATTENTION

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ARMSTRONG AEROSPACE MEDICAL RESEARCH LABORATORY

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This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

CHARLES BATES, JR.
Director, Human Engineering Division
Armstrong Aerospace Medical Research Laboratory

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The recent application of chaos theory to interpret various brain functions (see Huberman & Hogg, 1987) suggests it's usefulness for understanding potentially confusing and often conflictual results in the area of hemispheric processing. There appears to be inherent relationships between elements of chaos theory and the nature of hemispheric processes especially when viewed from an attentional resources perspective. The goal of this paper is to elucidate these relations by interpreting some data on hemispheric pattern recognition in a chaos theory framework. In order to interpret such data, theoretical models as well as specific concepts in attention, hemispheric processing, and chaos will be reviewed. A chaos-attentional model will be proposed along with certain rules of determination that predict the appearance of chaos in hemispheric processes. In conclusion, the paper will address some recent metaphors from Hofstadter (1979, 1985) that are supportive of this view of cognitive process.

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Preface

The research underlying this report was performed by the Harry G. Armstrong Aerospace Medical Research Laboratory, Human Engineering Division, Wright-Patterson AFB, Ohio in support of Work Unit 71841046, Strategic Information and Force Management. The research which led to this report was conducted with the expert support of Dr. Ron Katsuyama, a National Research Council Associateship appointment at AAMRL.

Also, the author gratefully acknowledges the support of other key personnel. Discussions with Dr. Keith Clayton, Professor of Psychology, Vanderbilt University, derived some of the seminal issues in chaos and its relationship to cognition. The support of the following Systems Research Laboratory, Inc. personnel was essential in conducting the underlying hemispheric asymmetry research. Thanks to: Bill McGovern who served as experimenter; Curt Mayrand and Brian Porter for their adept programming skills and advice; and Greg Boethe who provided timely insights and oversaw the engineering/hardware development.

I would also like to thank Mr. Walt Summers, Lt. Col. William Marshak, Dr. John Forester, and Mr. Don Monk, AAMRL/HE, for their support of this research.

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BASIC ISSUES IN HEMISPHERIC ASYMMETRY

Before delving head first into chaos, it is necessary (but not sufficient) to develop some of the issues and components that are pertinent to hemispheric processes. One may classify these processes based on three interrelated cerebral science research themes: 1.) cerebral functions, 2.) cognitive strategies, and 3.) cognitive demands. The respective elements of chaos will be related to these themes as required to demonstrate chaotic behavior. Each of these themes will now be described.

Cerebral Function

Traditionally, there have been many studies that act to associate a particular brain function with a given hemisphere (Sperry, 1974; Kimura, 1964; Gonzonaga, 1970). Typically, and often in a popularized overstated manner, these results would posit that the left hemisphere was responsible for language, analytical, and rational types of actions (Moscovitch, 1979); whereas, the right hemisphere was responsible for visuo-spatial, configurational, and emotional actions (Nebes, 1974). There is reason to believe that such specialization is authentic under prescribed conditions. However, cerebral function has often been discussed as an absolute, invariant truism.

This paper emphasizes the point that cerebral function is conditional and relative to operational performance characteristics. As will be shown, this conditional approach is highly related to a chaos interpretation. What is desired is an approach that focuses on hemispheric cooperation. In this sense, the aim is to look at functionality as a process that transpires between two brains wherein each brain has certain advantages and disadvantages to engage in certain actions, and each brain has a limited amount of resources which can be expended upon these actions. Hence, the model perpetrated is that functionality is an adaptive process which may shift from utilization of one hemisphere to the other given: the operational requirements of a task composite, the degree of relative specialization of the hemisphere initially presented the task, and the relative expenditure of resources for each hemisphere.

This model as posited in its rough format seems intuitively related to chaos models in terms of adaptation being a goal of the process. In chaos we see that chaotic behavior is necessary for a system to retrack itself from a cycle in order to adapt to obtain a greater purpose. Ford (1986) explains that chaos is dynamics freed at last from the shackles of order and predictability......systems liberated to randomly explore their every dynamic possibility.....exciting variety, richness of choice, a cornucopia of opportunity. Indeed, we believe that cerebral function shares these same accolades. The similarity here is in the idea that hemispheric shifting is necessary for the brain to adapt its function to the needs that are imposed upon it. As we shall see, it is this hemispheric shifting personified, that in fact is suggested as the evidence of a kind of chaotic turbulence within the cerebral system. The following two themes act to amplify some of these thoughts.

Cognitive Strategies

Inherent in the cooperation between hemispheres is the notion that certain cognitive strategies seem to be best performed by one hemisphere rather than the other. Please note that this does not preclude a hemisphere from using a certain strategy, but suggests that each hemisphere obtains advantages dependent on conditions. Currently, the assumption is that cognitive strategies may fall into two distinctive types: A.) piecemeal-feature recognition (Sergent, 1982), and B.) configurational-constructive processing (Ellis, 1983).

More specifically, piecemeal recognition is used when recognition can be based on a single feature, when there are familiar invariant patterns, and is identified by Klatzky (1986) as a picto-literal or linguistical strategy. Picto-literal refers to a representation that uses an analogue, depictive image as form; and has concrete, idiosyncratic details for content; and is encoded via visual perception and internal reperception processes. In contrast, configurational strategies are based upon recognition via a synthesis of various features, prototype construction, and are identified by Klatzky (1986) as a visuo-conceptual strategy. Visual-conceptual refers to representations which are descriptive, conceptual, propositional in form; abstract and categorical in detail; and are processed via perception, categorization, and interpretation.

Depending on various factors (e.g. cognitive demands), either of these types will be equivalent or one type will produce a definite advantage. As mentioned, it is assumed that these strategies are indigenous to one hemisphere or the other, (i.e., piecemeal recognition occurs in the left and configuration occurs in the right hemisphere). As we will see in the next section on cognitive demands, the utilization of a particular strategy is effected by single versus dual task conditions as well as many other factors.

Cognitive Demands

The cognitive demands produced within single and dual task paradigms are a determining factor for requiring the use of piecemeal or the configurational strategies. The main idea here is that a broad continuum of operational requirements can be created by precise control of these cognitive demands. This discussion of demands emphasizes the role of the stimulus material and what the subject does with it. Broadly, we define these demands as visuo-spatial image modulations. Some examples of modulation are transformation across perspective, image inversion, image derivation, image half-life, and image exposure duration. Note that the precise control of these modulations can create demands that range from low order to high order cognitive requirements that precipitate needs for certain cognitive strategies (e.g., an inverted face requires piecemeal recognition).

One of these image modulations (i.e., image familiarity) will be looked at in depth in the context of the forthcoming data on face recognition. Familiarity will be observed in chaos terms as the effecter of feedback whereby an image modulates change upon itself that acts to perturb the perceptual nature of the image. This is similar to Feigenbaum's ideas of recursion (see Glick, 1987, pp. 178-179). He felt that functions of functions began to work upon themselves in a self-referential way such that the behavior of one guided the behavior of another hidden inside it. Indeed, this aspect of feedback and recursion is built into hemispheric processing via image modulations and attentional resources. This component sets up this area of cognitive process to be interpreted within a chaos perspective.

Attention as a Cognitive Demand

Note that attention resources are also a different type of cognitive demand in that any given task may require a certain amount of resources to be processed. Attention has been theorized as a single capacitance (Kahneman, 1973), an econometric commodity (Navon & Gopher, 1979), and as multiple resource pools (Wickens, 1984). Of particular importance for this paper is the Friedman & Polson (1981) multiple resource framework; whereby each hemisphere is considered to be a separate, independent resource pool. Each hemisphere is viewed as quantitatively equivalent. Their predictions suggest that decrements abound if task composition overloads resources specific to one hemisphere. Thus, their type of theory moves toward using dual task arrangements in order to show decrements in conjunction with different types of task composition. Thus, under conditions of dual-task paradigms it is assumed that (dependent on task composition) attentional resources will be expended in different amounts. For example, Katsuyama & McNeese (1987) suggest that a LH advantage for name recognition would be greatest when a concurrent across-perspective face recognition task accesses the RH. We will return to these dual task arrangements later as a way of looking at predictions of chaotic behavior. Also note that the Friedman & Polson model does not allow interhemispheric transfer which is oppositional to the chaotic model proposed in this paper.

In this context it is important to consider attention as a cognitive demand that interacts with other image modulation demands to effect a certain pulse on operational requirements. This really sets up a foundation for the chaos-attentional model which we will be proposing.

Under single task requirements, there would be more options for transference to the opposite hemisphere for the most advantageous processing type. However, when dual task conditions are invoked then the processing resource factor figures robustly in the equation to determine the most effective cooperation between hemispheres. It is at this very point where chaos begins to play a major role in cooperation. It may be proposed within the context of hemispheric processing that chaos is defined as the necessity of phase transitions that appear when the attentional deficits of a directly accessed hemisphere are near exhaustion. The particular nature of the chaos experienced evolves as a function of the interplay among cerebral function, cognitive strategy, and cognitive demand at a given range of spatial-temporal focus.

CHAOS APPLIED TO THE CEREBRAL SCIENCE RESEARCH THEMES

For each theme identified, there are a number of concepts specific to the chaos literature (see Glick, 1987) that apply. Refer to Figure 1 which provides these correspondences. Within this figure there are two major thoughts which require attention. First, the appearance of chaos in cerebral systems is denoted by the presence of seemingly random hemispheric switching. Furthermore, the many conflictual findings within the hemispheric and attention literature may be considered as sampling of various chaotic states under different cognitive demands rather than looked upon as contradictory. This brings up the second thought which is an important theoretical issue for studying this area. Many of the previous studies take a decompositional-reductionist view of explaining right-and-left brain activity. Indeed, this has run amok in the popularized print, as many of the studies try to localize function. If one takes a more universalist approach that tries to understand what the entire system is doing, then cooperation through chaos emerges as large scale system behavior.

It may be useful to take a practical context of an example of chaos in physical systems and use it as an analogy for cerebral systems. The use of water undergoing different formations/forces and changes of state supplies a metaphor that is directly interpretable in a cognitive sense. Specifically, we will refer to waterfalls, boiling water, and water in a hydraulic system to make reference to chaos in cognition. The use of water has a intuitive appeal as some of the main treatments of attention models are hydraulic pressure models. This highlights an interesting flaw in these models that has "piggybacked" across disciplines. Fluid dynamicists often constructed formulations based on linear models of turbulence without trying to incorporate chaos. Unfortunately, these models only proved useful in elementary problem domains. When nonlinear concepts were suggested to be inherently present in complex hydrodynamic flow, the utility of the modeling process improved (see Lorenz, 1963). Yet, the attention theorists borrowed the naive linear based model and applied it to cognitive capacity (see Kahneman, 1973). Therein, much of this paper might be considered ways by which the naive (albeit linear) models of attention are transformed into nonlinear chaotic models that correspond to the models that address chaos in fluid dynamics. By entertaining a model with chaos, w^r provide a component which we feel addresses the interaction of the cerebral hemispheres.

THOUGHT: Appearence of random hemispheric switching and conflictual research findings may be evidence for chaotic behavior if observed at a compositional rather than a decompositional level.

CHAOS applied to COGNITIVE DEMANDS

- SELF SIMILARITY, FRACTAL NATURE with familiarity
- MANY STUDIES YIELD CONFLICTING DATA
- SMALL DEVIATIONS CREATE MAJOR CHAOTIC STATES
- RECURSIVE FEEDBACK functions occur (e.g., developmental familiarity)
- 1 or 2 POINT ATTRACTORS similar to channelized attention(LOCKING-IN)

CHAOS applied to COGNITIVE STRATEGIES

- SCALE INVARIANCE in continuum of processes
- BIFURCATION in transitional problem solving
- ADAPTIVITY must be emphasized through NON-LINEAR APPROACH
- INTRANSITIVITY is embedded in the cognitive strategies used

CHAOS applied to CEREBRAL FUNCTION

- PHASE TRANSITIONS between hemispheres
- LARGE SCALE SYSTEM behavior in brain (relate to scale invariance)
- CHAOTIC TURBULENCE and HYDRAULICS present in attentional switching
- SWIRLING FUNCTIONS engulf adaptive interhemispheric transfer and appears to envoke STRANGE ATTRACTORS
- ECONOMETRIC MODEL of attention may be internally derived via CHAOS
- CHAOS as a growth function for attention

ANALOGIES: order and chaos
symmetry and asymmetry
specialization and cooperation

Figure 1. A correspondence between chaos and hemispheric process

Hence, hemispheric switching examined vis-a-vis a boiling water metaphor would progress as follows. There are certain operational requirements that demand certain water temperatures. Within a given range, the behavior of the water is smooth and periodic, but as it approaches an impending phase transition a very small change in temperature will set off turbulent-chaotic motions in the water. Just as water reaches a critical point, attentional capacity of a given hemisphere may reach a level wherein a small cognitive demand sets off a chaotic transference of control to the opposite hemisphere for utilization of additional capacity and/or specialization advantage. Under situations of many complex ongoing activities, switching may evolve into another phase transition which might be expressed as swirling. Given development of automatic processing, a dropoff of chaos would be experienced. This would be another phase transition back into the original state of smoothness. This assumes once an activity becomes automatized, then the amount of attention necessary to sustain it is reduced.

At this point an examination of the data may help to extrapolate the chaotic nature of the cerebral hemispheres under certain conditions.

EXPERIMENTAL RESEARCH

Although it is not the intent of this paper to elaborate the specifics of the experimental designs of several studies undertaken to demonstrate hemispheric cooperation (see McNeese & Katsuyama, 1987; Katsuyama & McNeese, 1987; and Katsuyama, McNeese, & Schertler, 1987), it is instructive to sense what the studies consisted of and how they were conducted and how the variables were generally operationalized. Therein, a summary will suffice to explain the gist of this research. Please note that we only used male, right handed subjects with 20/20 vision in all studies undertaken. Also note that hemispheric processes were always studied in the context of face recognition such that cognitive strategies and demands are related to the subject processing human faces.

Design

The independent variables of main concern in these studies are: 1.) Transformation Across Perspective (faces are presented in either as frontal, 3/4, or side views), 2.) Hemispheric Access (LVF or RHV), and Familiarity (relative frequency per trial block). The dependent variables sampled were correct responses and reaction time. Note that these independent variables were manipulated in a variety of ways (i.e., within-subjects versus between subjects) and sessions were repeated at specified times after the initial session and the results were generally replicative. Each of these variables has historical antecedents but in order to avoid excessive article length we refer the reader to the original article (see Katsuyama, McNeese, & Schertler, 1987).

Procedure

Subjects were presented with 288 match-to-sample trials; wherein, a target face either appeared to the left or the right of the central visual field. They were then presented with four response choices, one of which was the initial target face. The given response choices per trial were either presented in the frontal, 3/4, or side orientation. The trials were divided into 4 blocks of 72 trials. Faces could reappear as targets 6 times and choice items 16-19 times per 288 trials. Target faces were composed from different models photographed and then digitized and stored in a

MacIntosh computer for access as required. These faces were presented for 133 msec. Subjects responded to stimulus presentation by pressing the appropriate key on their keypad, whereupon their choice and reaction time were recorded.

Results and Interpretation

Most of the results in the other studies were supportive of data presented in Figure 2. Note the replication after subjects were brought back for another session 1 to 2 weeks later. Without detailing out the very specific results, we may summarize by stating that there is a significant Hemisphere Accessed X Perspective X Familiarity interaction, $F(6,66) = 4.62$, $p < .001$. It is the nature of this interaction which we submit as evidence of chaotic phase transitions between the left and right hemispheres.

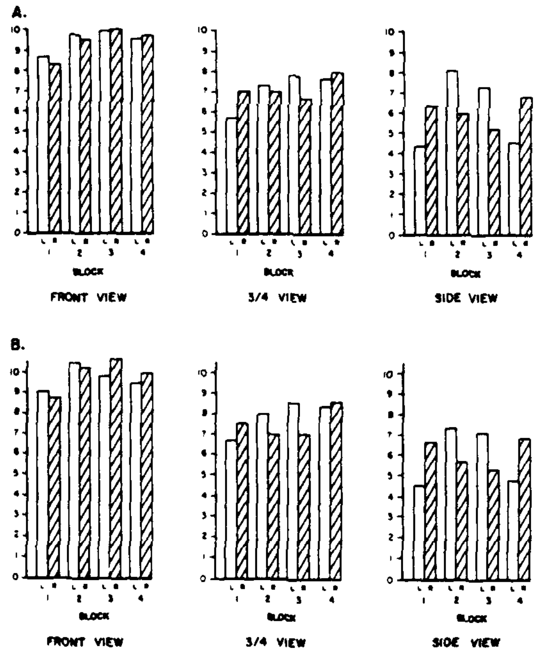

Figure 2. Mean correct recognition responses on session 1 (panel A) and session 2 (panel B) according to visual field (L= left visual field; R= right visual field), trial block, and viewing perspective.

An inspection of Figure 2 indicates that hemispheric advantages were greater on the 3/4 and side than on the frontal perspective trials. On the 3/4 and side perspective trials, an initial RVF/LH advantage was replaced by a LVF/RH advantage on Blocks 2 and 3. Subsequently, on Block 4 the hemispheric advantage was eliminated (for the 3/4 perspective trials) and replaced by RVF/LH advantage (for side perspective trials). It is interesting to look at the findings for the side view particularly. When faces are relatively unfamiliar, subjects utilize the left hemisphere; whereas, once familiarity begins to develop (in blocks 2 and 3) the right hemisphere is advantages. Finally, after familiarity is developed (block 4) subjects revert back to left hemisphere usage for an advantage.

An interpretation of these results hinges on the effects of familiarity. There are two aspects of familiarity that must be delineated and they each make opposite predictions with respect to hemispheric advantage. The first might be termed invariant frequency. By this we mean that a given stimulus is exposed a certain number of times across all trials such that subjects develop familiarity with the invariant perceptual form. This is a developmental phenomenon which pursues the creation of prototypes upon repeated exposures. When prototypes are used for recognition, as we have stated, there is support for right hemisphere advantages. What is difficult to determine is the time at which processing efficiency changes from feature recognition to prototype recognition. If this point was known precisely (rather than sampled after relative levels of frequency), then one might predict even more extreme levels of shift between right and left hemisphere adaptation.

Another aspect of familiarity reported in the literature (Marzi, et al, 1986) revolves around variant exposures under different environmental contexts. Specifically, famous faces are examples of this type of familiarity. This type of familiarity has shown advantages for the left hemisphere. The shift from RH to LH processing in Block 4 may suggest that this type of familiarity was experienced after the subjects experienced a face repeatedly in both target and response choice roles.

We believe that a chaos view also is entwined with aspects of familiarity (as an image modulator) by proposing that familiarity acts as a feedback loop between the subject and the stimulus item. This loop undergoes small incremental changes that voles different attractions between the stimulus and the subject. Now, where does chaos figure in this description? These changes in the loop are small but at certain points major shifts in advantage are observed in the data (e.g. LH to RH advantage from block 1 to block 2). We suggest that these are evidence of phase transitions that occur between hemispheres.

At certain points in the development of familiarity, there are these rapid, chaotic shifts to utilize the "other" hemisphere. The data just presented are provided as evidence that a turbulent shifting of processing occurs from one hemisphere to another and may be described as a chaotic-yet cooperative-function. Other demands that interact between the subject and the task may act in ways similar to familiarity to bring on the onset of chaos. One demand, attentional resources, in particular will weigh heavily in projection of the chaos model. Attention becomes a salient factor in dual task paradigms just as familiarity is in single task paradigms. The focus will drift more toward attention as it is much more of a large scale system component that predicates reasons for chaos to occur. Hence, at this point we think there is data that shows cerebral chaos in normal subjects. What remains is to create more refined connections of chaos elements, postulate some reasons for this chaos, and propose rules of engagement that predict when chaos might crystallize in cerebral systems.

DISCUSSION

Cerebral Hemispheres and Their Chaotic Relationships

Upon a closer look at the data, there is really a type of order within the random fluctuations obtained. The fluctuations obtained must be viewed as fluctuations in either hemispheric function or attentional function or an artifact of the studies procedure and design. Note that artifacts might however be symptomatic of the underlying structure of the problem. A case in point is that the slightest change in presentation time may set off vast changes in the phenomenon being studied. This is highly related to chaos concepts so it may be that laterality theorists are trying to over-systematize hemispheric brain function when in fact it is truly chaotic and signified by a wholistic large scale behavior.

Many of the models we have described take these highly specialized views. For instance, the Wickens (1984) model breaks attention down into resources, Friedman & Polson's (1981) model looks at each hemisphere as a resource pool, Kinsbourne (1980) looks at functional cerebral spaces, and Kahneman (1973) looks at attention as a single capacitance that applies as needed. The point is that these models act to try and impose a systematized order (even when the order is not present) by a process akin to taking the wheat off the chaff. But the chaff gets discarded. Often, the dynamics are "mock" dynamics in that the randomness is rationalized away as being due to the experimenter, equipment, or procedural error; or it is explained as being a function of the individual differences of subjects. This latter statement was a favorite of ours in trying to account for the ease at which hemispheric function tended to vacillate from left-to-right hemispheric function. What we are proposing is that the chaff may be necessary in order to interpret the wheat. The results we interpreted may only be understandable in terms of the large scale behavior as evidenced in terms of cooperation between each hemisphere as a function of the task's demands. Our so-called randomness may be the onset of chaotic behavior in the cognition.

Indeed we were at odds as our data seemed to have an order underlying the chaos and also an overall pattern of response. It was as if some of the localized tendencies at certain points would go into complete phase transitions that changed the overall understanding of the system. Indeed, we now think that the cooperation between brain hemispheres might involve different phase transitions that are onset by chaotic turbulences in attention. It is crucial here not to take a decompositional view but rather an activationist view, whereby, the dynamic qualities are kept sacrosanct rather than disposed of. This might be analogous to understanding a waterfall. The true essence is not captured by describing the force vectors at any given point as water is governed by opposing droplets, but only by sensing the entire turbulent motion that successively cascades upon itself. By focussing on the strange attractors, one captures a bit of the way the system acts.

As a beginning to this paper, we began with the observation that within hemispheric asymmetry there are shifts between RH & LH performance. The underlying patterns of developing familiarity are assumed responsible for this finding. The shifts in hemispheric performance may be specific phase transitions that occur due to an interaction in pattern familiarity and required cognitive level of function. The nature of hemispheric shifts change as a function of the demands imposed on the cognitive system. Refer to Figure 3 where a graphic depiction of this process is shown as the chaotic-attention model of hemispheric cognition.

Seemingly the system transforms itself (a self adaptive, autopoietic function) into a new state which can conduct itself differently. The two hemispheres underlie this transformation and thus show differing performance levels under various impinging constraints. Whether these chaotic transformations are due to functional space or resource pools, is in question. Or more importantly, is there a fractal nature to attention? Assumptions related to the need to change state are required. One is that there is a critical bottleneck in capacity whenever dual tasks are required and the overload requires the system to do something to adapt yet still be intact to complete actions. Note here that when a system does not adapt, it can acquire symptoms that tend to channelize it's behavior such that the system can only deal with one or two modes of response. This seems conceptually similar to the 1 or 2 point attractor. Yet, when there is enough capacity to adapt, chaotic behavior ensues.

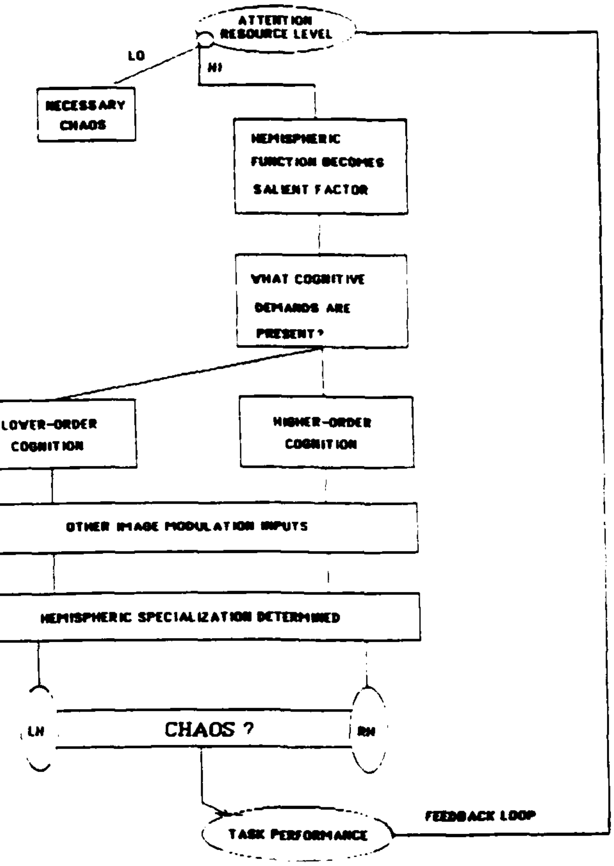

Figure 3. A chaotic-attention model of hemispheric cognition

The system may go into chaos when threshold levels are obtained without notice. Chaos can occur suddenly without warning. Perhaps chaos is a regenerative process that allows perceptual learning to take place or allows attention to grow in the sense that it is redistributed in the goal of adaption. The effects of familiarity thus impact either the redistribution of attentional processes or effect perceptual learning inter-hemispherically. All in all, the order that lies beneath the chaos falls out in terms of large scale behavior and the hemispheric control process that adapts the system to its environment. The fractal nature seems to involve self-similarity related to familiarity. Could attention have a fractal nature that causes it to be self-similar across different vantage points? Does attention grow through this self-similar nature? How can one conceptualize fractal natures other than in visual terms? Also, relate the idea that once a pattern or activity is familiarized or automatized, attention is freed for other actions. Perhaps the self-similar brain state is one that is invariant at the large scale level, across phase transitions. The brain uses the hemispheres as scaler changes with chaotic patterns, but in the end the brain is invariant across scales as it is adapting to it's requirements. The structure of attention could be self-similar and recursive.

Prediction of Chaotic States

Based on the data presented and the model proposed in Figure 3, certain high level predictions of chaos may be proposed. This is an example of how a new interpretation of data can act to generate a new direction in experimentation. These predictions will be provided for both single and dual task paradigms. The types of task compositions one creates will perturbate these predictions. The performance losses are based on costs for interhemispheric transfer (-), cost associated with a disadvantaged hemisphere processing a task (--), and cost associated with a hemisphere trying to process a task with inadequate resources (---); or a combination thereof. We state these predictions in terms of the face recognition task for single task predictions, and face recognition plus a linguistic task (e.g. antonym-synonym match) for the dual task. Please note that we have collapsed 3/4 and side view faces and now identify them as "non-frontal" faces. Thus, the predictions are as follows:

<u>Single Task Paradigm</u>

CONDITION 1A: FRONTAL FACES to LH or RH
(assume frontal faces consume less resources than nonfrontal faces)

1. If attentional resources are available and the face is directly accessed by the LH or RH, then no transfer is necessary. Therefore, predict SMOOTH PHASE STATE.

2. If attentional resources are unavailable in LH v RH and the face is directly accessed by RH v LH, then transfer to opposite hemisphere for further processing. Therefore predict baseline PHASE TRANSITION STATE.

3. If face cannot be transferred due to masking or other effects, then process by directly accessed hemisphere. Therefore predict SMOOTH PHASE STATE.

CONDITION 2A: NONFRONTAL FACES to LH

1. If the LH is directly accessed then-if possible-transfer to RH with minor performance loss; therefore predict expectant PHASE TRANSITION STATE---- else---- process in LH with major performance loss/ predict SMOOTH PHASE STATE.

CONDITION 3A: NONFRONTAL FACES TO RH

1. If RH is directly accessed and face has not developed familiarity, then no transfer is necessary. Therefore predict SMOOTH PHASE STATE.

2. If RH is directly accessed but face has developed familiarity, then transfer to the LH with minor performance loss. Therefore predict PHASE TRANSITION STATE.

<u>Dual Task Paradigm</u>

(In order to emphasize the attentional demands the effects of familiarity on faces may be dropped out for purposes of brevity)

CONDITION O: LINGUISTIC TASK ONLY

1. If linguistic task only, then only the LH is utilized. Therefore predict SMOOTH STATE. (the linguistic is always centrally presented)

CONDITION 1B: (FRONTAL FACES to LH) + LINGUISTIC

1. If LH is active with linguistic task and a frontal face is directly accessed by LH and attentional resources are approaching critical level, then transfer face to RH if possible. Therefore predict PHASE TRANSITION STATE with minor performance loss compared to condition 1A----else----experience overload condition in the LH. Therefore predict NO CHAOS but obtain poor

performance.

2. If LH is active with linguistic task and a frontal face is directly accessed by LH and attentional resources are not getting low, then do not transfer to RH. Therefore predict SMOOTH STATE.

CONDITION 2B: (FRONTAL v NONFRONTAL FACES to RH) + LINGUISTIC

1. If LH is active with linguistical task and the face is directly accessed by RH, then no transfer as optimal performance for each task exists. Therefore predict SMOOTH STATE with optimal performance.

2. If the face has developed familiarity, then transfer to LH with significant performance drop, therefore predict PHASE TRANSITION with much less than optimal performance----else----forego transfer with poor performance, predict NO CHAOS but expect poor performance.

CONDITION 2C: (NONFRONTAL FACE to LH) + LINGUISTIC

1. If LH is active and a nonfrontal face is directly accessed by LH and attentional resources are approaching a critical level, then transfer face to RH, therefore predict PHASE TRANSITION with performance decrease in face recognition task and performance increase in linguistic task----else----fail miserably on both tasks, therefore predict NO CHAOS and failure.

2. If face has developed familiarity and attentional resources are not getting low, then do not transfer. Therefore predict SMOOTH STATE but linguistic performance may decrease in comparison with conditions 1A or 2B.

These predictions may now be subjected to an empirical test to see if a chaos-attentional model will be able to account for the results.

CONCLUSIONS

There has been much conjecture regarding the role of chaos in attention and hemispheric processing. Possible relationships were projected, data was interpreted from this new perspective, and a chaotic-attentional model was formulated with predictions of when chaos could occur. Two points need to be put forth in conclusion. First, one must realize that the data used to formulate many of the relationships was based on a static, tachistoscopic experimental procedure. The ecological validity and generalization of these results will truly mold this model in the correct direction. Some may question the model in terms of split brain subjects who purportedly live normal lives without hemispheric transfer. At this point, there are discrepancies regarding the capabilities of such subjects as well as methodological problems with the population itself as one must understand why these subjects had a commissurotomy in the first place.

Second, we tend to think that in an ecological setting that multiple, recursive spreading activations within a hemisphere and across hemispheres are more the norm than the exception. It may be possible to apply some of the new electrophysiological techniques (e.g., electro-magneto encephalographic measurement) to measure inter-hemispheric transfers across certain time ranges as subjects participate in the type of tasks described in the experimentation. This is taking more of Hofstadter's (1979,1985) collective systems dynamical viewpoint. Basically, he suggests that the brain is a community composed of smaller communities wherein swirling functions commandeer the relative adaptive flow among these communities. Although the data presented here do not allow such a generalized interpretation, future research needs to approach cerebral and cognitive interaction in terms of large scale system behavior rather than continually espousing the reductionist promise.

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